

High Efficiency Isolated AC-DC Converter with Gradationally Controlled Voltage Inverter for On-Board Charger

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ABSTRACT

A new isolated AC-DC converter for an on-board charger has been developed. It consists of an AC-DC converter with Gradationally Controlled Voltage Inverter and an isolated zero-voltage-switching DC-DC converter. To make these converters cooperate efficiently over the wide range of operating voltage conditions, we developed an optimized converter control. As a result, the new isolated AC-DC converter can operate with power conversion efficiency of over 94%.

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INTRODUCTION

Recent tightening of emission control regulations in many countries directs attention to electrical vehicles (EVs) as zero emission vehicles and car manufactures accelerate the development of EVs. Charging a high-voltage Li-ion battery is one of the major functions of an EV. There are two charging systems, one is a "normal charge" via an AC power supply from the power grid and the other is a "quick charge" using a DC power supply. For the normal charge system, an on-board charger (OBC) is generally built into the EV.

The OBC converts AC input to DC output for the high-voltage battery and the input and the output should be isolated to prevent users from electric shock or accidental fire. Therefore, an isolated AC-DC converter for the OBC generally consists of an AC-DC converter (non-isolated) and an isolated DC-DC converter. Conventional OBCs use a single phase power factor correction (PFC) type for the AC-DC converter and a full-bridge type for the DC-DC converter, and their power conversion efficiency is under 90%. The AC electric energy consumption rate, which is calculated in the ratio of the mileage to the charging energy from the power grid, is a key factor for EVs and higher efficiency is required for the OBCs. This paper describes our developed high efficiency isolated AC-DC converter and key technologies for the OBC.

Figure 1 shows the configuration of the converter and applied technologies in our OBC. Gradationally Controlled Voltage Inverter (GCVI) is applied to the AC-DC converter.

GCVI is our original multi-level inverter, which outputs controlled stepwise voltage with series inverters and brings lower power losses and lower noise. GCVI is applied to inverter equipment such as voltage sag compensators [1], UPSs [2] and power conditioners for photovoltaic power generation systems [3]. We have been developing a converter with GCVI [4], and succeeded in applying GCVI to our OBC for the first time. The zero-voltage-switching (ZVS), [5] a soft-switching for low switching losses is applied to the isolated DC-DC converter for our OBC. In addition, we developed an optimized converter control technique which can achieve high efficiency over a wide range of input-output conditions.

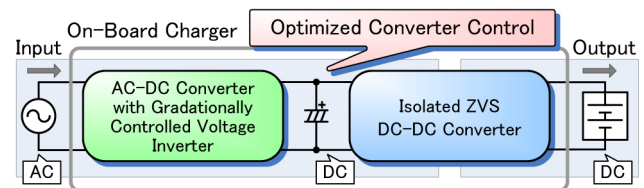


Figure 1. Converter configuration and applied technologies in the on-board charger

APPLIED TECHNOLOGIES

AC-DC Converter with Gradationally Controlled Voltage Inverter

Gradationally controlled voltage inverter

As shown in Figure 2, Gradationally Controlled Voltage Inverter (GCVI) consists of series connected voltage-type inverters. The sub voltages of the individual inverters (V_0 , $2V_0$) have a binary number relationship with each other. GCVI can output multi-level voltage controlled by these outputs (V_1 , V_2).

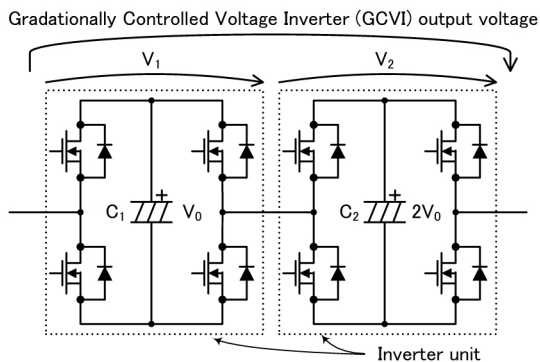


Figure 2. Basic diagram of GCVI

Figure 3 shows the example of waveforms by GCVI. Each inverter unit can output 3 level voltages (-1 , 0 , 1). In this case, GCVI can output a quasi-sinusoidal waveform by 7 level voltages.

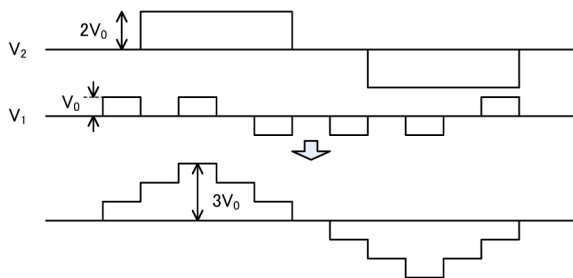


Figure 3. Output waveforms of GCVI

Table 1 shows the relationship between the total output voltage and each inverter output voltage. In each inverter unit, if the output voltage and the current have the same polarity, the sub capacitor is discharged. And if they have a different polarity, the sub capacitor is charged. Additionally, Table 1 shows that there are two output patterns when the total output voltage of the inverters is " V_0 " and " $-V_0$ ".

Table 1. Relationship between the total output voltage and each inverter output voltage

	Total output voltage						
	$-3V_0$	$-2V_0$	$-V_0$	0	V_0	$2V_0$	$3V_0$
V_2	$-2V_0$	$-2V_0$	0	$-2V_0$	0	$2V_0$	$2V_0$
V_1	$-V_0$	0	$-V_0$	V_0	0	$-V_0$	V_0

Figure 4 shows two patterns of schematic diagrams for the total output voltage V_0 , indicated in Table 1. Pattern A shows that the C_1 is discharged. And pattern B shows that the C_1 is charged and the C_2 is discharged. The sub voltage V_0 can be controlled by selecting these two patterns. Therefore, GCVI can regulate the capacitor voltage of each inverter unit so that one capacitor voltage becomes twice that of another one.

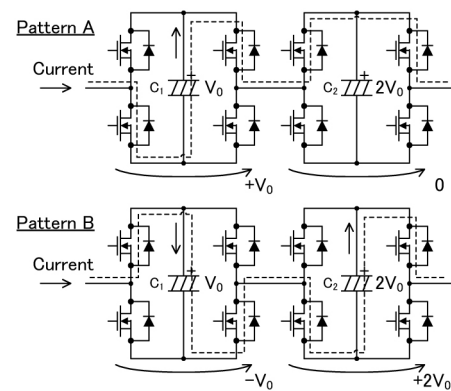


Figure 4. Schematic diagrams for the total output voltage V_0

Operating principles of AC-DC converter

Figure 5 shows the schematic diagram of the GCVI AC-DC converter. It is composed by connecting GCVI to the AC grid of a general AC-DC step-up converter in series.

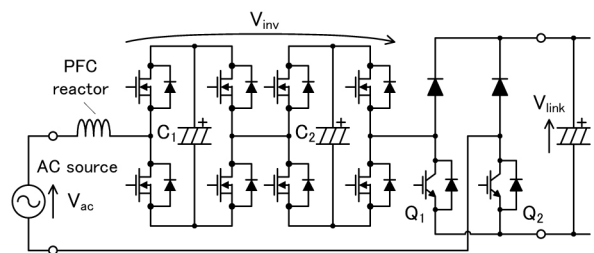


Figure 5. Schematic diagram of the GCVI AC-DC converter

GCVI can control AC current to be a sinusoidal waveform (in phase with the AC input voltage) for power factor improvement. GCVI outputs the voltage with level V_0 amplitude by Pulse-Width-Modulation (PWM), so it can reduce the ripple current caused by switching and can improve the current controllability, in order to control the